



## **Sensitivity of the SNCR Process to Furnace Process Variables<sup>1</sup>**

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The Selective Non-Catalytic Reduction (SNCR) of combustion source  $\text{NO}_x$  emissions involves the injection of a reagent into the furnace to reduce the  $\text{NO}$  content via ammonia or urea-based homogeneous gas-phase reactions. Although, theoretically,  $\text{NO}_x$  reduction in excess of 60 percent is achievable under ideal conditions of residence time and flue gas temperatures of 1400 to 2100°F, actual system performance is affected by furnace and SNCR system operating conditions. The numerical results show that at a given temperature, urea injection rates and  $\text{NO}_x$  baseline emissions have the largest impacts on SNCR system performance. Furnace excess  $\text{O}_2$ ,  $\text{CO}$  level and residence time have a lesser effect in the higher temperature region known as the “right-side” of the  $\text{NO}_x$  reduction versus temperature curve. Un-reacted  $\text{NH}_3$  emissions (ammonia slip) are mostly impacted by urea usage and release temperature.

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## INTRODUCTION

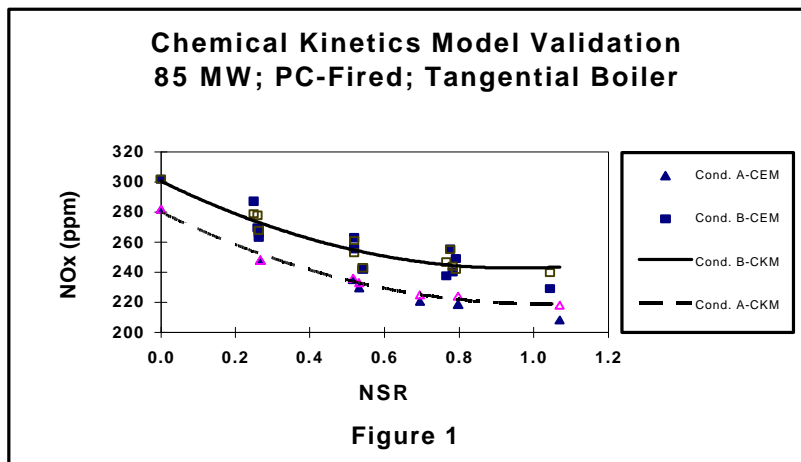
Nitrogen oxides ( $\text{NO}_x$ ) are known to be primary precursors to acid rain and to contribute to the formation of regional tropospheric ozone. The Selective Non-Catalytic Reduction (SNCR) process is one of the technologies recognized by the EPA for  $\text{NO}_x$  removal. This technology has received extensive testing in utility boilers, and it involves the gas-phase reaction of a nitrogen-based reagent, typically ammonia ( $\text{NH}_3$ ) or urea, with  $\text{NO}_x$  at elevated temperatures to form molecular nitrogen and water vapor. The reagent decomposition is a chemically complex process, including the amino ( $\text{NH}_2$ ) groups and overall free radical reactions.

Theoretically,  $\text{NO}_x$  reduction in excess of 60 percent is achievable under ideal conditions of residence time and flue gas temperatures in the range of 1400 to 2100°F. Higher  $\text{NO}_x$  reductions are limited by un-reacted  $\text{NH}_3$  (ammonia slip). In the field, system performance is affected by furnace and SNCR system operating conditions. In a full scale boiler or furnace, the reduction of nitrogen oxides by urea injection is dependent on a number of boiler specific parameters. In particular, these include the stoichiometry of the chemical process (baseline  $\text{NO}_x$  and reagent injection ratios), carbon monoxide and excess  $\text{O}_2$  levels, and the temperature and velocity field immediately downstream of the point of injection, since these parameters determine mixing requirements and the actual temperature history and residence time available for reaction.

## NUMERICAL MODEL

A homogeneous gas phase computer model was developed for the prediction of flue gas  $\text{NO}_x$  reduction and ammonia slip by urea. The numerical model describes an ideal, one-dimensional plug flow, with the temperature history approximated by a linear profile. The model further assumes the reagent has already been atomized and the droplets are fully evaporated. The physics of this problem is completely defined by a set of ordinary differential equations. Urea decomposition was modeled as an instantaneous one-step breakdown to  $\text{NH}_3$  and  $\text{HNCO}$ . The detailed chemical kinetics scheme used is composed of 105 reversible reactions and 24 species. This scheme includes the ammonia and isocyanic acid oxidation reactions and the wet-CO oxidation reactions.

Figure 1 shows the comparison between reduced  $\text{NO}_x$  measurements for a coal-fired, tangential boiler, with a nominal full load of 85 MW, and the model results. The data correspond to urea single zone injection. Input to the theoretical model included CEM measurements of  $\text{NO}_x$ , CO,  $\text{CO}_2$ , and  $\text{O}_2$ ; urea injection flow; and temperature information obtained with an optical temperature probe. The theoretical model predicts reduced  $\text{NO}_x$  emissions fairly well up to NSR's of 0.8 for two different boiler operating conditions. The deviation between the measured and calculated reduced  $\text{NO}_x$  level increases at higher urea feed rates. No  $\text{NH}_3$  slip was associated with the temperatures used in these measurements.



## PARAMETRIC RESULTS AND DISCUSSION

The chemical kinetics model was used to parametrically determine the effect of furnace parameters: flue gas temperature conditions, excess  $O_2$ , CO level, baseline  $NO_x$  residence time, and NSR (related to urea injection rate), on the urea-based SNCR  $NO_x$  reduction versus temperature curve. The numerical results show that, for the range of typical utility boilers, the two most important factors are the temperature and NSR, followed by the initial  $NO_x$  level, and CO and  $O_2$  concentrations in the furnace. The NSR effect is important at the “right-side” of the curve, where SNCR systems are more likely to operate, however, the position of the temperature window and the shape of the low-temperature side of the curve are not affected by NSR (Figure 2). Figure 2 shows that ammonia starts to slip at temperatures lower than plateau temperatures. In these cases, larger values of NSR are associated with larger ammonia slips for fixed operating conditions. The level of baseline  $NO_x$  also affects SNCR system performance most strongly at higher temperatures, although, the maximum  $NO_x$  reduction is not affected. Figure 3 shows that a reduction in baseline  $NO_x$  from 1.3 to 0.4 lbs/MBtu, at a release temperature of 2000°F, can affect the percent  $NO_x$  reduction by up to 30 percent.

Consideration also needs to be given to the axial temperature distribution in the furnace and to the process residence time. Temperature distribution was expressed in this work as a temperature gradient, in units of degrees per second. The temperature profile does not impact the percent  $NO_x$  reduction on the “right-side” of the  $NO_x$  reduction versus temperature curve. This is due to the fact that at higher temperatures, the reaction rates are so fast that in theory, achievable  $NO_x$  reduction occurs close to the urea release location. This indicates that the process is not chemically controlled but determined by the characteristic times associated with the gas and spray fluid dynamics. Residence time, becomes a factor, particularly at lower furnace temperatures. The model indicates that the residence time required for complete reaction is independent of the amount of reagent used, and for typical design release temperatures is of the order of 0.25 seconds.

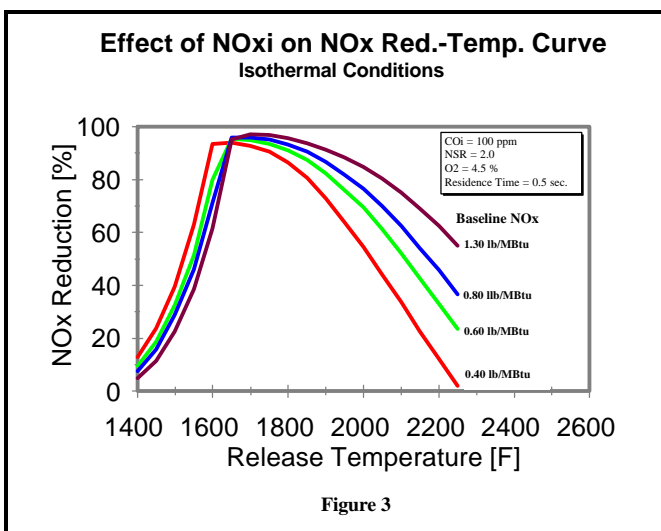
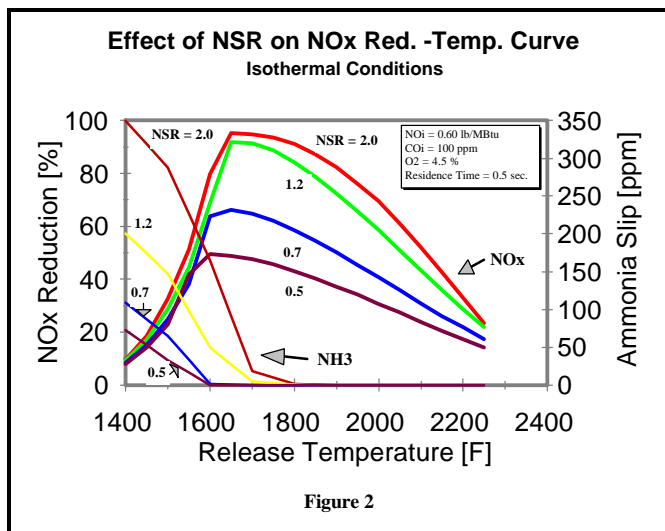


Figure 4 shows plots of the term  $1000/T$ , where  $T$  is the release temperature in Kelvins, versus the natural logarithm of the reduced  $\text{NO}_x$  level, for fixed values of  $\text{O}_2$ ,  $\text{CO}$ , and  $\text{NSR}$  are. The temperature range used in the Figure corresponds to the higher temperature region known as the “right-side” of the  $\text{NO}_x$  reduction versus temperature curve. The approximate linearity of the curves indicates SNCR process performance can be correlated with furnace combustion variables using an Arrhenius type correlation. It also indicates the possibility of finding an effective activation energy for the process as well as orders of reaction for  $\text{NSR}$ ,  $\text{CO}$ , and  $\text{O}_2$ .

